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Comparison of the radiopacity of NeoSealer Flo, Sure-Seal Root, Guttaflow Bioseal, and AH Plus Jet: An in vitro study

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Purpose: To compare the radiopacity of two calcium silicate-based sealers (NeoSealer Flo and Sure-Seal Root), a calcium silicate particle-containing silicone (GuttaFlow Bioseal), and an epoxy resin-based root canal sealer (AH Plus Jet) using digital radiography.

Methods: Five samples (1 ± 0.1 mm height, 10 ± 0.1 mm diameter) were prepared for each material tested. After the samples were completely set, digital radiographs of the samples and an aluminum stepwedge were taken. The mean gray values of each sample and aluminum step were calculated using the ImageJ program, and the values were converted into equivalent aluminum thicknesses. Kruskal-Wallis and post-hoc Dunn tests were used to analyze the data.

Results: The radiopacity values of NeoSealer Flo (4.9 mm Al), GuttaFlow Bioseal (4.84 mm Al), and Sure-Seal Root (4.36 mm Al) were significantly lower than those of AH Plus Jet (10.83 mm Al) ($p < 0.0001$), but there were no significant differences among the three ($p > 0.05$).

Conclusion: Although the calcium silicate-based and calcium silicate particle-containing silicone-based sealers exhibited lower radiopacity than the resin-based sealer, the radiopacity values of all root canal sealers tested met the minimum Al standard values advised by the International Organization for Standardization and the American National Standards Institute/American Dental Association.

Keywords: Calcium silicate; epoxy resin; radiopacity; root canal sealer; silicone.

Introduction

Optimum root canal filling materials need to possess appropriate physicochemical properties as well as adequate radiopacity to distinguish them from neighboring anatomical structures like tooth and bone, and other dental materials (1,2). In addition, the radiopacity of root canal sealers can be used to determine the quality of endodontic treatment or to monitor areas of internal resorption, root fractures, and lateral canals (2,3).

Higginbotham (1967) pioneered the investigation of the radiopacity of various root canal sealers and core materials used in root canal filling (4). Eliasson and Haasken (1979) employed aluminum with an equivalent thickness to produce optical radiographic density measurements, creating a standard for comparison in radiopacity research (5). Beyer-Olsen and Orstavik (1981) utilized an optical densitometer to measure the light transmission through the mate-

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rial, determining the radiopacity of root canal sealers and translating this into an equivalent aluminum thickness by comparing it with a radiographically measured aluminum step wedge (penetrometer) (2). These studies were used as a reference by the International Standards Organization (ISO) and the American National Standards Institute/American Dental Association (ANSI/ADA) to establish minimum radiopacity values for root canal filling materials.

Per ISO standards, root canal filling materials are required to have a radiopacity equivalent to a minimum of 3 mm of aluminum (6). The ANSI/ADA standards specify that endodontic filling materials should exhibit a radiopacity difference of at least 2 mm of aluminum when compared to dentin and bone (7). Aluminum was selected as the reference material due to its radiopacity being comparable to that of dentin (8).

Recently, novel root canal sealers have been introduced as innovative filling materials. These sealer compositions were developed by adding different radiopaques and calcium silicate at different ratios. NeoSealer Flo (Avalon Biomed, Houston, TX, USA) is a premixed calcium silicate-based canal sealer containing the bioactive ingredients tricalcium silicate (< 25%), dicalcium silicate (< 10%), calcium aluminate (< 25%), calcium aluminum oxide (grossite) (< 6%), tricalcium aluminate (< 5%), and the radiopaque tantalum oxide (tantalite; < 50%). The manufacturer also reports trace amounts of calcium sulfate (< 1%). NeoSealer Flo does not cause tooth discoloration because it contains tantalite as a radiopaque agent. Furthermore, according to the manufacturer, the root canal sealer has a radiopacity equivalent to that of 6 mm Al (9).

Sure-Seal Root (Sure Dent Corp., Gyeonggi-do, Korea) is another premixed injectable calcium silicate-based root canal sealer containing calcium aluminosilicate, calcium sodium phosphosilicate, a thickening agent, and radiopaque zirconium oxide. According to the manufacturer, it is biocompatible and highly antibacterial, bonds perfectly to gutta-percha and dentin without shrinkage, and has excellent radiopacity (10). It is also preferred for its low surface tension and highly hydrophilic structure, which allows easy penetration into accessory canals and the root canal system (11).

GuttaFlow Bioseal (Coltene Whaledent, GmbH Co. KG, Langenau, Switzerland) is a cold-flow filling system that combines a root canal sealer and gutta-percha in a single product. It has a similar formulation to GuttaFlow, a silicone-based root canal sealer, but contains calcium silicate particles as an extra bioactive component, which promotes biological repair and encourages periapical healing (12). The manufacturer's data sheets do not provide radiopacity values (13).

AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany) is an epoxy resin-based root canal sealer composed of bisphenol-A epoxy resin, bisphenol-F epoxy resin, calcium tungstate, zirconium oxide, silica, and iron oxide pigments in paste A, and dibenzyldiamine, aminoadamantane, tricyclodecane-diamine, calcium tungstate, zirconium oxide, silica, and silicone oil in paste B. The manufacturer stated that the root canal sealer has a radiopacity equivalent to 13.6 mm of aluminum (14). When analyzing the physicochemical properties of root canal sealers, new materials are typically compared to a clinical reference. AH Plus, an epoxy resin-based root canal sealer, is frequently regarded as the gold standard (15).

As far as we know, there is limited information available regarding the radiopacity of NeoSealer Flo and Sure-Seal Root (16). In addition, there are very different results in the literature regarding the radiopacity of GuttaFlow Bioseal root canal sealer (12,17-22). Therefore, the aim of this study was to evaluate and compare the radiopacity of two calcium silicates (NeoSealer Flo and Sure-Seal Root), a calcium silicate particle-containing silicone (GuttaFlow Bioseal), and an epoxy resin-based root canal sealer (AH Plus Jet) using digital radiography.

Materials and Methods

The manuscript of this laboratory study has been written according to the Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines (23). Figure 1 presents a visual representation of the study design and its outcomes. NeoSealer Flo, Sure-Seal Root, GuttaFlow Bioseal, and AH Plus Jet were used as root canal sealers in this study. Table 1 provides the composition and manufacturers of the materials.

Sample Preparation

Polytetrafluoroethylene Teflon molds with a height of 1 ± 0.1 mm and an internal diameter of 10 ± 0.1 mm were used to prepare the samples. The molds were positioned on a glass plate covered by a cellophane sheet. Following the manufacturer's instructions, the root canal sealers were mixed and then placed into molds. For each material, five samples were prepared. To obtain a smooth surface on the top of the samples, a second glass plate covered with cellophane was placed on the materials. According to the manufacturer's instructions, the setting times for NeoSealer Flo, Sure-Seal Root, GuttaFlow Bioseal, and AH Plus Jet root canal sealers were 11 hours ± 1 hour, 150 minutes, 12–16 minutes, and 24 hours, respectively (9,10,13,14). The samples were kept in an incubator at 37°C with 95% humidity for three times these setting times (24). Once set, the samples were removed from the molds and their

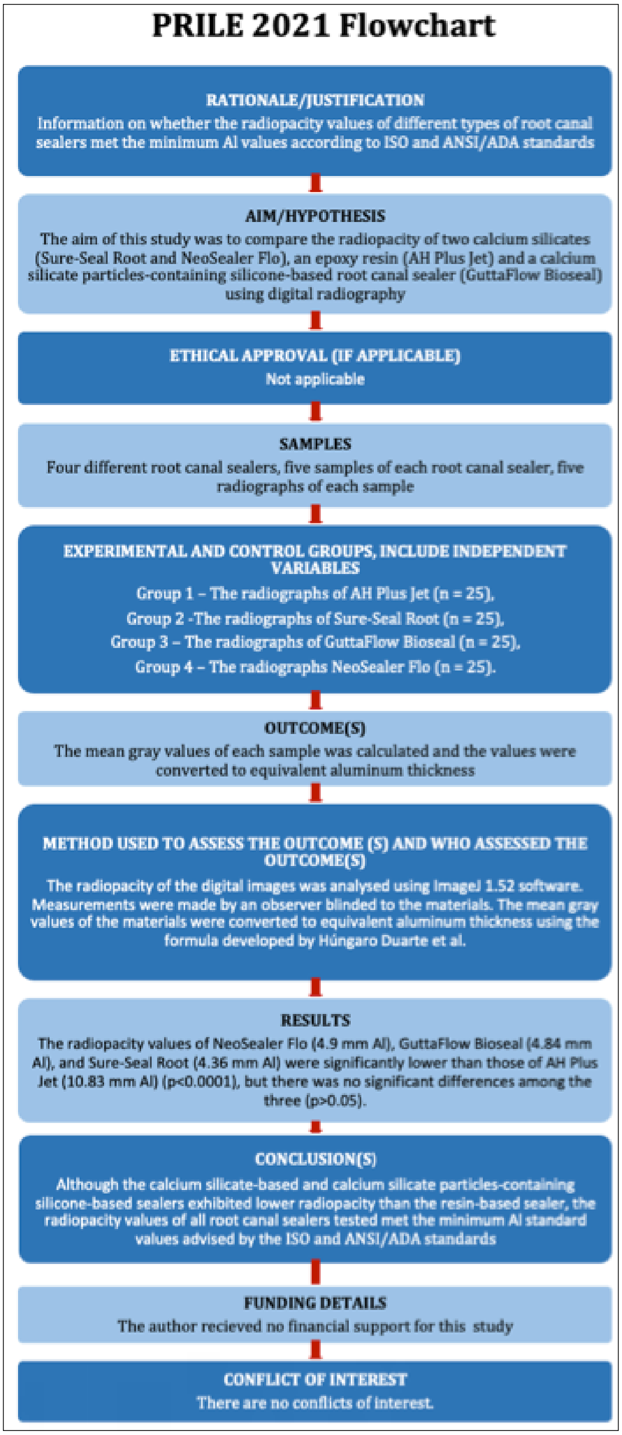

Fig. 1. PRILE 2021 flowchart.

thickness was controlled using a digital caliper (SHAN Electronic Digital Caliper).

Digital Radiography

A 14-step aluminum stepwedge with 1 mm step increments was utilized to assess the radiopacity of the root canal sealers. The contents of aluminum were Al: 99.12, Fe: 0.47, Mg: 0.41, and Cu: < 0.1 (weight%) according to ISO 6876. Digital radiographs of the prepared samples and the aluminum penetrometer were taken (Fig. 2). The intraoral radiography device (Kodak 2100) was set to 60 kVp, 7 mA, and an exposure time of 0.32 sec. The focus-object distance was set to 30 cm, with the angle between the phosphor plate surface and the X-ray arm adjusted to 90°. Five radiographs were taken from each sample (n = 25).

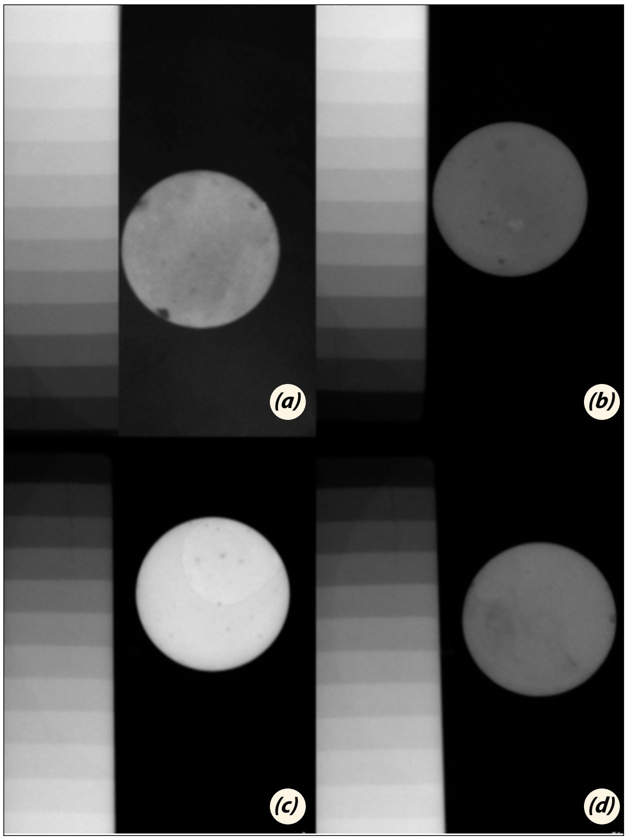

Fig. 2. Digital radiographs of the NeoSealer Flo (a), Sure-Seal Root (b), AH Plus Jet (c), GuttaFlow Bioseal (d) root canal sealers and an aluminum penetrometer.

Evaluation of Digital Radiography

The radiopacity of the digital images was analyzed using ImageJ 1.52 software (National Institutes of Health, Bethesda, MD, USA). To eliminate the differences that may occur when comparing sealers and to evaluate the consistency of the radiopacity of the sealers within themselves, each radiographic image and each step of the penetrometer were evaluated five times, and the mean gray values (MGVs) were calculated and averaged. When selecting the regions, the average gray areas were calculated from the regions without air bubbles in the material. The average of 25 images was then calculated for each material. Measure-

Table 1. Composition of root canal sealers and their manufacturers

Materials	Compositions	Manufacturers
NeoSealer Flo	Tantalite (50%), tricalcium silicate (25%), calcium aluminate (25%), dicalcium silicate (10%), tricalcium aluminate (5%), calcium sulfate (1%), grossite	Avalon Biomed; Houston, TX, USA
Sure-Seal Root	Calcium aluminosilicate, calcium sodium phosphosilicate, zirconium oxide, thickening agent	Sure Dent Corp., Gyeonggi-do, Korea
GuttaFlow Bioseal	Gutta-percha powder, polydimethylsiloxane, platinum catalyst, zirconium dioxide, calcium salicylate, nano-silver particles, colouring, bioactive glass ceramic	Coltene Whaledent, GmBH Co. KG, Langenau, Switzerland
AH Plus Jet	Paste A (amber colour): bisphenol-a epoxy resin, bisphenol-f epoxy resin, calcium tungstate, zirconium oxide, silica, iron oxide pigments Paste B (white colour): dibenzyldiamine, aminoadamantane, tricyclodecane-diamine, calcium tungstate, zirconium oxide, silica, silicone oil	Dentsply DeTrey GmbH, Konstanz, Germany

ments were made by an observer blinded to the materials. The MGVs of the materials were converted to equivalent aluminum thicknesses using the formula developed by Húngaro Duarte et al. (25).

Statistical Analysis

SPSS for Windows 17.0 software was used to analyze the data. Whether the data conformed to a normal distribution was determined by the Shapiro-Wilk test. Then, the data were analyzed with Kruskal-Wallis and post-hoc Dunn tests at the significance level ($p < 0.05$).

Results

The radiopacity values of the tested root canal sealers are shown in millimeters of aluminum in Table 2. The radiopacity values of the materials decreased in the following order: AH Plus Jet (10.83 mm Al), NeoSealer Flo (4.9 mm Al), GuttaFlow Bioseal (4.84 mm Al), and Sure-Seal Root (4.36 mm Al). The radiopacity values of the NeoSealer Flo, GuttaFlow Bioseal, and Sure-Seal Root canal sealers were significantly lower than those of AH Plus Jet ($p < 0.0001$), but there were no significant differences among the three ($p > 0.05$). All tested root canal sealers met the radiopacity requirements of the ISO and ANSI/ADA standards.

Discussion

According to the ISO and ANSI/ADA, the radiopacity of root canal materials should be at least equal to 3 mm of aluminum. In this study, although two calcium silicate-based root canal sealers (NeoSealer Flo and Sure-Seal Root) and one calcium silicate particle-containing silicone-based root canal sealer (GuttaFlow Bioseal) had lower radiopacity values than the epoxy resin-based root canal sealer (AH Plus Jet), all the root canal sealers compared met the advised minimum Al values.

Additionally, materials that meet the minimum radiopacity of approximately 3 mm Al may not be clearly visible in radiographs due to the superposition of anatomical structures on the root (26). In this context, the two calcium silicate-based root canal sealers and the calcium silicate particle-containing silicone-based root canal sealer had radiopacity values of around 4–5 mm Al, while the epoxy resin-based root canal sealer had radiopacity values of 10.83 mm Al, indicating that the radiographic visibility of these root canal sealers is at an ideal level.

The differences in radiopacity among the root canal sealers compared in this study may be attributed to the different radiopacity agents used for each material and the different

Table 2. Radiopacity values (mean ± standard deviation) of the tested root canal sealers (mm Al)

Materials	Radiopacity values (mm Al) (Mean ± standard deviation)
NeoSealer Flo	4.9 ± 0.21^b
Sure-Seal Root	4.36 ± 0.28^b
GuttaFlow Bioseal	4.84 ± 0.23^b
AH Plus Jet	10.83 ± 0.52^a

Different letters (^{a,b}) indicate significant differences between radiopacity values of root canal sealers ($p < 0.05$).

amounts and ratios of these agents (27). It has also been noted that higher atomic numbers and molecular weights enhance the radiopacity of the material. The atomic numbers and molecular weights of bismuth, tungstate, tantalum, barium, and zirconium are 83 (208.98 g/mol), 74 (293.82 g/mol), 73 (180.95 g/mol), 56 (137.33 g/mol), and 40 (91.22 g/mol), respectively (28).

AH Plus was equivalent to 10.83 mm Al and had the highest radiopacity. The inclusion of calcium tungstate along with zirconium oxide in AH Plus may have given the material a higher radiopacity (27). Tanomaru-Filho et al. (18) investigated the physicochemical properties and volumetric changes of AH Plus, Total Fill BC Sealer, and GuttaFlow Bioseal root canal sealers, reporting a radiopacity of 9.42 mm Al for AH Plus. Tasdemir et al. (29) compared the radiopacity of GuttaFlow, ADseal, AH Plus, Diaket, and Epiphany root canal sealers and reported that the radiopacity of AH Plus was 10.4 mm Al. Gümrü et al. (30) assessed the radiopacity of MTA-based root canal filling materials and found the radiopacity value of AH Plus to be 9.7 mm Al (30). In accordance with these previous studies, our study found the radiopacity value of AH Plus to be 10.83 mm Al.

NeoSealer Flo had the second highest radiopacity value of the root canal sealers tested at 4.9 mm Al. Although NeoSealer Flo contains high-atomic-weight tantalite, the presence of 40–50% of this material may have resulted in significantly lower radiopacity values compared to the AH Plus root canal sealer (16). Only one study evaluating the radiopacity of NeoSealer Flo was found in the literature (16). This study investigated the physicochemical properties and bioactivity of premixed calcium silicate-based root canal sealers containing different amounts of calcium silicate and reported that the radiopacity of NeoSealer Flo was equivalent to 5.5 mm Al (16). In addition, Bio-MM, another calcium silicate-based root canal sealer with tantalite as a radiopaque agent like NeoSealer Flo, also showed radiopacity equivalent to 4.5 mm Al (31). Based on this information, it can be said that the radiopacity values of root canal sealers containing tantalite as a radiopaque agent are approximately equivalent to a value between 4 and 5 mm Al.

GuttaFlow Bioseal, a calcium silicate particle-containing silicone-based root canal sealer, had an equivalent radiopacity of 4.84 mm Al. The radiopacity of this root canal sealer is due to the zirconium dioxide and nanosilver particles it contains (17,32). A review of the literature showed that the radiopacity values of GuttaFlow Bioseal varied widely, such as 3.94, 4.27, 5.08, 5.41, 5.62, 7.02, and 8.87 mm Al equivalent (12,17-22). These differences may be due to the lack of standardization between the studies in material thickness, irradiation settings (irradiation time, kV, mA, object-focus distance), film speed, type of imaging technique, method of density measurement, and aluminum alloy (33,34).

Sure-Seal Root, another calcium silicate-based root canal sealer containing zirconium oxide as a radiopacity agent, had a radiopacity value of 4.36 mm Al. Zirconium has been added to root canal sealers to make calcium silicate materials more biocompatible and to allow the release of more and longer-lasting calcium ions (35,36). This may have resulted in the low radiopacity of root canal sealers containing low atomic weight zirconium dioxide. To the best of our knowledge, although no study has reported the radiopacity of Sure-Seal Root, other calcium silicate-based root canal sealers such as Bio-C Sealer and BioRoot RCS, containing zirconium, have shown radiopacity values of 4.5 (37) and 4.9 (24) for Bio-C Sealer, and 2.9 (38) and 4.74 (37) for BioRoot RCS. Together with these, the radiopacity results of Sure-Seal Root in our study may shed light on and fill the gap in the literature.

The overlap of soft tissue, tooth, and bone structures is specific to the clinical situation and is one of the limitations of radiopacity studies. In studies where material is added to the tooth structure, the age of the tooth, the degree of calcification, or different root diameters may cause variability in the radiopacity of dentin samples between individuals (30,39) and may result in different radiopacity values between studies (20,40). In addition, the ISO and ANSI/ADA standards specify aluminum as the minimum radiopacity criterion. Therefore, tooth samples were not used as a control group in our study. The study also had limitations, such as not evaluating the radiopacity of the gutta-percha and not performing EDX to compare the elemental content of the root canal sealers. Further studies should determine the percentage of all elements, including the radiopacifier elements, in root canal sealers.

Conclusion

Although NeoSealer Flo, GuttaFlow Bioseal, and Sure-Seal Root canal sealers had lower radiopacity values than AH Plus Jet, within the study's limitations, all tested root canal sealers met the minimum Al standards advised by the ISO and ANSI/ADA. Clinicians should be mindful of the radiopacity of the root canal sealer used to assess the quality of the root canal filling, distinguish the material from surrounding anatomical structures, and ascertain the amount of root canal filling material removed during retreatment.

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